Temporal decorrelation by power-law adaptation in neocortical neurons

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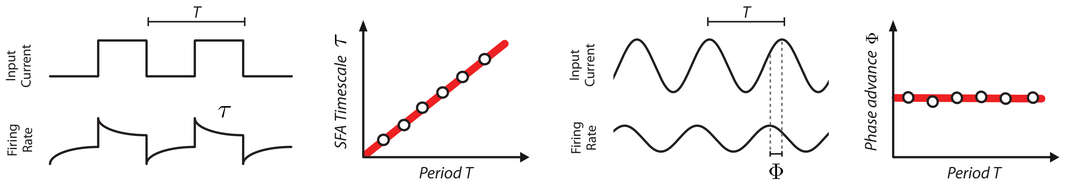
Abstract

Spike-frequency adaptation is widespread in the central nervous system, but its functional role remains unclear. In neocortical pyramidal neurons, adaptation manifests itself by an increase in neuronal firing threshold and by adaptation currents triggered after each spike. Combining electrophysiological recordings with modeling, we found that these adaptation processes last for more than 20 seconds and decay over multiple time scales according to a power-law. The power-law decay associated with adaptation mirrors and cancels the temporal correlations of input current received in-vivo at the soma of L2/3 somatosensory pyramidal neurons. These findings suggest that, in the cortex, spike-frequency adaptation causes temporal decorrelation of output spikes (temporal whitening), an energy efficient coding procedure that, at high signal-to-noise ratio, improves the information transfer.

Scale-free adaptation in neocortical pyramidal neurons

(Lundrstom et al., *Nature Neuroscience 2008*)

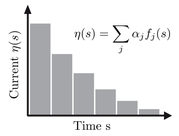


Spiking neuron model (GLIF)

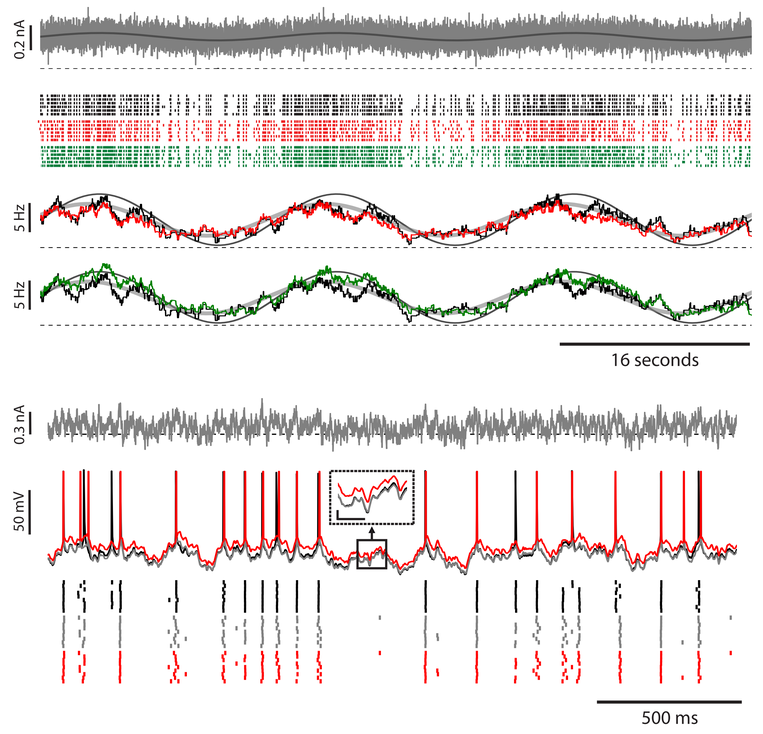
$$\lambda(t) = \lambda_0 \exp\left(\frac{V(t)-V_T(t)}{\Delta V}\right)$$

$$V_T = V_T^* + \sum_{\hat{t}_j<t} \gamma(t-\hat{t}_j - T_{\text{ref}})$$

$$C\dot{V} = -g_L(V-E_L) + I_{\text{ext}} - \sum_{\hat{t}_j<t} \eta(t-\hat{t}_j - T_{\text{ref}})$$



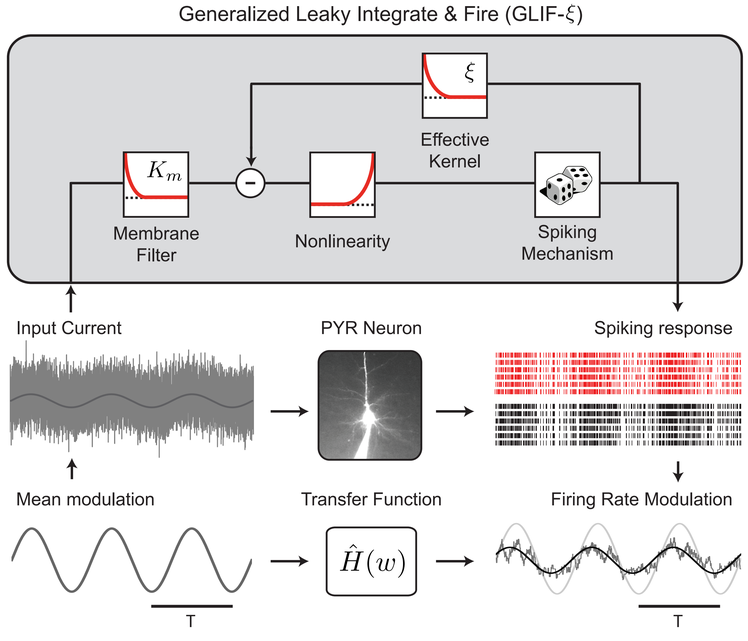
The GLIF model captures the spiking activity of neocortical neurons on multiple timescales



Experiemental approach

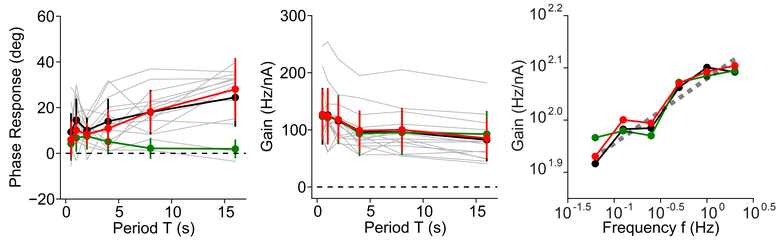
L5 pyramidal neurons are stimulated in-vitro with noisy currents modulated by slow sinusoidal averages. Spike-frequency adaptation is tested on multiple timescales by measuring the firing rate fluctuations in respose to different frequencies of modulation (0.5 < T < 16 s).

Goal: explain scale-free adaptation using a Generalized Integrate & Fire model !

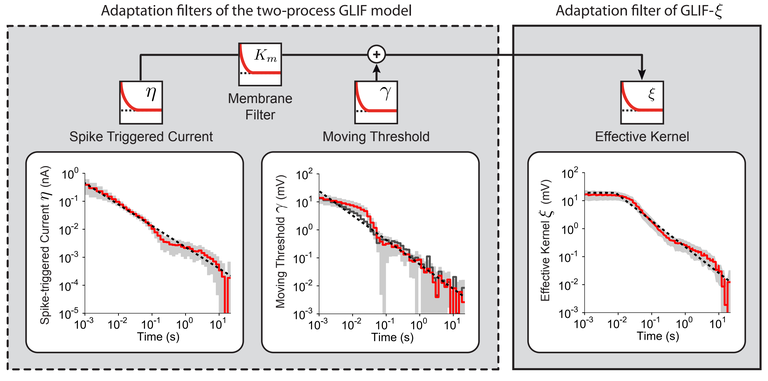


Scale-free adaptation is mediated by two power-law spike-triggered processes

The firing rate modulation revelas spike-frequency adaptation on multiple timescales



Each action potential triggers both an adaptation current and a movement of the firing threshold that last for more than 20 seconds and decay according to a power-law.



Power-law adaptation is near-optimally tuned to perform temporal whitening

'Natural stimuly' received by pyramidal neurons in behaving mice are scale-free. Power-law spike-triggered adaptation mirrors and cancels the temporal correlations of the input.